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**ENCYCLOPEDIA
OF POLYMER
SCIENCE AND
ENGINEERING**

VOLUME 3

**Cellular Materials
to
Composites**

			Polyethylene sheet		Polypropylene			Polyurethane					Silicone						
			Extruded ^a	Cross-linked ^b	Unmodified ^c	Modified ^c	Sheet ^d	Super soft ^e	Standard cushioning ^f	Carpet underlay ^g	High resilience type ^h	Polyvinyl chloride ⁱ		Liquid ^j	Sheet ^k	Sheet ^l			
ethylene extruded ^a	closed	closed	43 closed	26-28 closed	64-96 closed 550	64-96 closed 206	10 4.8	24 open 2.1	16 open 4.4	24 open 5.7	34 open 15.7	26 open 1.9	40 open 4.6	56 closed	112 closed	96 open	272 open	160 open	400-544 closed
241		690	41		830	344		45	88	118	258	79	103	10.3	24	3.4	36 at 207°		
60		60	276	276-480	1100	1380	138-275	181	160	205	135	200	160			220	227	310	550-700
			50		25	75		50		40		65	62						
17.5	26	51	26					2.6	3.3	4.4	3.7	2.6	2.4						
82	82	82	82	79-93	135	135	121									350	260	232	
0.058	0.058	0.058	0.040-0.049	0.036-0.040	0.039	0.039	0.039							0.035	0.040		0.078	0.086	

Fraction Open Cells. An important characteristic of the cell structure is the extent of communication with other cells. This is expressed as fraction open cells. When many cells are interconnected, the foam has a large fraction of open cells and is termed an open-celled foam. Conversely, numerous noninterconnecting cells result in a large fraction of closed cells and is termed a closed-celled foam.

The nature of the opening between cells determines how readily gases and liquids can pass from one cell to another. Because of variation of this flow, a single measurement of fraction open cells does not fully characterize this structural variable, especially in a dynamic situation.

Gas Composition. In closed-celled foams the gas phase in the cells can contain blowing agent (so-called captive blowing agent), air, or other gases generated during foaming. Thermal and electrical conductivity can be profoundly influenced by the cell-gas composition. In open-celled foams the presence of air exerts only a minor influence on the static properties but does affect the dynamic properties such as cushioning.

Mechanical Properties

In mechanical properties (qv), rigid foams differ from flexible foams. The tests used to characterize them are therefore different as are their application properties. In the last decade a separate class of high density, rigid cellular polymers have become commercially significant. They are called structural foams (density $> 0.3 \text{ g/cm}^3$).

Rigid Cellular Polymers. Compressive strength and modulus are readily determined and have been widely used to characterize rigid plastic foams.

Rigid cellular polymers generally do not exhibit a definite yield point, but rather an increased deviation from Hooke's law as the compressive load is increased (Fig. 2). The compressive strength is usually reported at some definite deflection (5 or 10%). The compressive modulus is extrapolated to 0% deflection unless otherwise stated. Structural variables that affect the compressive strength and modulus of a rigid plastic foam are, in order of decreasing importance, plastic-

mer particles (unex-
containing a blowing
re is placed in a mold
able particles to foam
ne molding. A typical
e polyurethane foam

melt or solution that
plastic particles and
se give the required

6), whereas cellulose
stals are dispersed in
y(vinyl chloride) can
The leatherlike ma-
of salts (221) or by
as a gel with many

spherical, intercon-
tribution have been
eparation (223). If a
perature but soluble
icroporous polymer.
bient temperatures,
be extracted. These
s controlled-release

States began in the
aterial. For cushion
These materials are
irability, and good
ich are used in au-
40 kg/m³.

their final shape or
ade bun that is cut
s are finding wide
erlay, textile lam-

g agent is carbon

dioxide, which is formed by the reaction of water and toluene diisocyanate. Softer foams with lower densities require an auxiliary blowing agent such as chloro-fluorocarbon-11 (CFC-11, trichlorofluoromethane) or methylene chloride (see also BLOWING AGENTS).

In the United States flexible polyurethane foam is generally sold by the board foot (2.5 cm × 30 cm × 30 cm). Typical densities are 18.5–32.0 kg/m³ for conventional foams and 40.0 kg/m³ for high resilience (HR) foam. Foam prices are usually double the cost of the starting materials for standard grades. Typical foam prices in 1982 were ca \$2.75/kg or \$0.36/m at 18.5 kg/m³ to \$0.63/m at 32 kg/m³. The U.S. consumption by market area is given in Table 8.

Table 8. U.S. Flexible Polyurethane Foam Consumption, 1981^a

Market area	10 ³ t
furniture	195
transportation	107
carpet underlayment	73
bedding	64
scrap	36
packaging	16
miscellaneous	11
<i>Total</i>	<i>522</i>

^a Ref. 225.

Flexible polyurethane foams are produced from long-chain, lightly branched polyols and a diisocyanate, usually toluene diisocyanate (TDI), to form an open-celled structure with free air flow during flexure. During manufacture these foams are controlled for proper density (13–80 kg/m³) and load-bearing characteristics. Long, flexible polymer chains with relatively few cross-links are produced. The elastomeric polymer acquires additional toughness by the presence of hard segment urea-based polymers. Intermolecular hydrogen bonding plays a role in foam hardness. Triols are preferred but diols and tetrols are also used. The polyol chain initiator, usually glycerine or trimethylolpropane, determines the functionality of the final product. Propylene oxide (PO) is polymerized onto the initiator to form a long-chain triol with an equivalent weight of 1000–1500. These chains are characterized by pendant methyl groups and terminal secondary hydroxyl groups that provide the reactivity needed for slab-foam manufacture. Ethylene oxide (EO) can be used in conjunction with PO to modify the polyether chain by reducing the pendant methyl groups; this modification is called a hetero polyol. Addition of a mixed PO–EO feed forms a random hetero, whereas batch EO feed forms a block hetero polyol. Ethylene oxide can produce primary hydroxyl groups at chain termination; this is known as EO capping. Such polyols show higher reactivities toward isocyanates; this type is required for molded-foam production.

Another type of polyol contains a dispersed solid phase of organic chemical particles (226–228). The continuous phase is one of the polyols described above for either slab or molded foam. The dispersed phase is formed in the polyol by

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 - Hold portable CD player in place
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 - In infant bathtubs to keep baby steady
 - Make non-skid gloves or mitts
 - Under throw rugs
 - Line medicine cabinet
 - Texture painting
 - On top of washer & dryer
 - High chair trays
 - In magazine racks
 - Travel size shower mat
 - Shower seats
 - Keep seat cushions in place
 - Toddler's shoe bottoms
 - Under pet dishes
 - Refrigerator shelves
 - Grooming mat for pets
 - Under shop equipment
 - Under kitchen seat cushion
 - On the backs of frames to prevent crooked pictures
 - Under phones
 - Door knob gripper
 - Dollies
 - Under knick-knacks
 - Under coffee mugs
 - Under templates for sewing
 - Cabinets in motor homes/boats
 - Under fish filters to quiet the humming
 - On sewing machine top
 - Counter tops
 - On broom/mop/rake handles
 - In tool boxes
 - Under office items
 - On edge of stencils
 - In bottom stove drawer of electric range
 - Between mattresses to keep them from sliding around
 - Remove filters from camera lenses
 - To cover bulletin boards
 - Replace footies on PJ's
 - To earthquake-safe valuables in California homes
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